The Impact of Phosphorus Fertilizer Placement on Crop Production[1]

R.E. Karamanos[1], N. A. Flore[2], J. T. Harapiak† and F. C. Stevenson[3]

[1] Koch Agronomic Services, LLC, Calgary, Alberta; [2] Crop Production Services., Calgary, AB; [3] 142 Rogers Road, Saskatoon, SK, S7N 3T6, Canada; †Deceased

Abstract

Improved phosphorus (P) fertilizer management is viewed as a way to improve yields in highly productive cropping system. A study was conducted at numerous sites during the 1990's to assess plant density and yield of canola (*Brassica napus* L.), barley (*Hordeum vulgare* L.), spring wheat (*Triticum aestivum* L.), and winter wheat respond to greater P fertilizer rates (0, 15, 30, 45, and 60 kg P ha^{-1}) when seed placed and side banded. We did find that canola stand was insensitive to rates of P tested when banded, but greater rates of seed-placed P caused stand thinning. It is thought the compensatory growth of canola was the reason why canola yield did not respond to P treatment. Both barley and winter wheat yielded most when the greatest rates of P were applied. Spring wheat showed a similar response when P was side banded, thus indicating improved tolerance with P placed away from seed. Therefore, spring wheat was the only crop that fit with our hypotheses; side banding P will allow crops to respond positively to greater rates of P fertilizer. The fact the cereal crop density was unresponsive to P management indicates that seedlings show early-season better tolerance than canola. Unlike canola, yield-forming factors for cereal crops responded to greater rates of P.

Introduction

In a constant effort to improve yields and profitability of highly productive cropping system, nutrient management remains a cornerstone practice to assist in this endeavor. Phosphorus (P) is a major nutrient applied by producer and sufficient P supply early in the growing season is necessary maximize crop yields (Grant et al. 2001). Grain crops, especially canola, germination and emergence can be reduced if too much phosphate is placed with the seed (Henry et al. 1995). Phosphorus is one of the least mobile macronutrients in prairie soils, and immobilized P from previous year's applications is not readily mineralized over time (Black 1982; Cowell and Doyle 1993). Therefore, producers constantly must ensure that crops have adequate levels of available P.

The application of P fertilizer is a long-standing fertilizer management practice that generally, but not always, improved grain crop productivity especially under cool, moist growing conditions (Alberta Agriculture and Food 1997; Manitoba Agriculture, Food and Rural initiatives 2006; Saskatchewan Agriculture and Food 2006). With P fertilization, it can be a critical

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decision what rate is chosen as the seedlings of some crops, such as canola (*Brassica napus* L.), are sensitive for greater rates of seed-placed P fertilizer. Provincial recommendations are normally based on 15 to 17% seedbed utilization (SBU) and the ‘safe rate’ (no establishment stand reduction) of seed-placed P fertilizer thus established for a medium textured soil was about 20 kg P ha^{-1} for canola and about 45 kg P ha^{-1} for barley (*Hordeum vulgare* L.) as well spring or winter wheat (*Triticum aestivum* L.) (Alberta Agriculture and Food 1997; Manitoba Agriculture, Food and Rural initiatives 2006; Saskatchewan Agriculture and Food 2006). Of course, these values are modified as SBU changes, becoming less at narrow and greater at wider SBU values.

Phosphorus fertilizer placement can have a varied effect on crop responses, depending on the crop and environmental conditions. Spring wheat responded similarly to side-banded and seed-placed P, except under notably dry growing conditions where side-banding improved wheat responses (Mooleki et al. 2010). Seed-placed and side-banding resulted in similar winter wheat yields (Campbell et al. 1996). Lafond et al. (2001), however, found that side-banded versus seed-placed P fertilizer applied at rates greater than 9 kg P ha^{-1} increased winter wheat grain yield at half the sites. This same study showed no response to P fertilizer rate or placement method when soil residual P was greater than 34 kg P ha^{-1}. Another winter wheat study compared side-banded to seed-placed application of phosphate fertilizer applied at rates from 0–60 kg P_2O_5 ha^{-1} and showed a positive yield response to P rate occurred at all sites, but rates of 30 and 45 kg P_2O_5 ha^{-1} rates often maximized yield (Karamanos et al. 2003). At one of five sites, a P rate x placement interaction occurred because the 45 kg P_2O_5 ha^{-1} rate maximized yield when side-banded and 60 kg P_2O_5 ha^{-1} rate maximized yield when seed-placed. The probability of a profitable yield benefit declined with increasing fertilizer rate or soil test P level. Barley yields were greater during cool years with seed-placed P than with banded P (Karamanos et al. 2008). For canola, plant stand was denser when P was side-banded versus seed-placed (Lemke et al. 2009). The same study showed that seed yield and seed N uptake was improved with seed-placed P fertilizer. McKenzie et al. (2003) observed a 10% yield increase due to application of seed-placed P fertilizer, and this increase occurred at two-thirds of the cereal (barley and spring wheat) sites and just under half of the canola sites.

The diversity in P recommendations amongst the western Canadian provinces combined with the introduction of new varieties and the expansion of direct seeding practices has necessitated an assessment of major crops to P fertilizer. Karamanos et al. (2003) commented that the ability to side-band or seed-place P fertilizer with increased seed bed utilization may fulfill the need for application of greater rates of P than the ones currently recommended for prairie soils. The objectives of this study were to assess the response of two cereal crops and canola to range of soils P fertilizer applied at different rate in a side-band or seed-placed to show that side banding P will allow crops to respond positively to greater rates of P fertilizer.

Materials and Methods

Site Description and Experimental Design

A series of experiments with four small grain crops were established at locations in Saskatchewan and Alberta from 1991–2000. Soil characteristics and a description of the sites are summarized in Tables 1 and 2.

The experimental design for each site (location by crop combination) by crop combination was a RCB with 3-6 replicates. Each plot generally was 1.37 m wide (0.91 m at one site) by 7–7.6 m long. The treatment design included a factorial arrangement of two method of P fertilizer

Table 1. Soil characteristics of study sites at number locations in Alberta and Saskatchewan, 1991-2000.

Crop	Location	Year	0-15 cm					
			OM[z] (%)	Texture	pH	EC mS cm^{-1}	NO_3 - N ($kg\ ha^{-1}$)	P ($kg\ ha^{-1}$)
Canola	Bentley, AB	1993		Loam	6.3	0.43	9.0	12.0
	Irricana, AB	1996		Loam	6.6	0.40	19.0	12.0
	Irricana, AB	1997	4.5	Loam	6.2	0.20	4.0	12.0
	Carstairs, AB	1997	4.0	Loam	6.7	0.40	9.0	14.5
	Red Deer, AB	1997	4.9	Clay loam	7.6	0.50	9.0	19.5
Barley	Airdrie, AB	1991	7.0	Loam		1.26	7.0	2.0
	Crossfield, AB	1991	7.9	Loam		1.17	7.0	1.0
	Carstairs, AB	1991	7.2	Loam		0.95	14.0	6.0
	Irricana, AB	1993	6.7	Loam		1.12	8.0	9.0
	Airdrie, AB	1991	6.9	Loam		0.98	10.0	4.0
	Irricana, AB	1996		Loam	6.6	0.40	19.0	12.0
	Red Deer, AB	1996		Clay loam	8.1	0.40	4.0	2.0
	Yorkton, SK	1996	5.3	Clay loam	7.9	0.60	16.0	10.0
	Irricana, AB	1997	4.5	Loam	6.2	0.20	4.0	12.0
	Red Deer, AB	1997	5.8	Clay loam	6.5	0.40	13.0	13.0
	Red Deer, AB	1997	6.9	Clay loam	7.8	0.70	6.0	3.0
	Olds, AB	1997		Loam				
	Red Deer, AB	1998		Clay loam				
Wheat	Crossfield, AB	1991	7.7	Loam		1.21	15.0	3.0
	Crossfield, AB	1993	7.4	Loam		0.98	22.0	4.0
	Barons, AB	1997	3.4	Loam	6.8	0.50	7.0	28.0
	Enchant, AB	1998	2.3	Loam	8.0	1.60	3.0	22.0
Winter wheat	Irricana, AB	1998	5.8	Loam	7.1	0.70	11.0	15.5
	Irricana, AB	1999	3.9	Loam	6.2	0.50	8.0	9.0
	Herronton, AB	2000	4.6	Clay	6.0	0.20	11.2	16.5
	Irricana, AB	2000		Loam				
	Herronton, AB	1999	3.0	Clay	6.2	0.20	4.7	17.7

[z] Analyses prior to seeding: organic matter (Thiessen and Moir (1993); hand texturing; pH and EC in 1:2 soil:water suspension (Hendershot et al. 1993, Janzen 1993); soil NO_3-N (Laverty and Bollo-Kamara 1988); bicarbonate-extractable P (Olsen et al. 1954).

Table 2. Description of study sites at number locations in Alberta and Saskatchewan, 1991-2000.

Crop	Location	Year	Previous crop	Seeding date	Harvest date	Precipitation[z] (mm)
Canola	Bentley, AB	1993	barley	May 13	Sep 22	231
	Irricana, AB	1996	fallow	May 19	Sep 11	236
	Irricana, AB	1997	wheat	May 14	Sep 2	250
	Carstairs, AB	1997	barley	May 7	Sep 21	276
	Red Deer, AB	1997	barley	May 12	Sep 8	273
Barley	Airdrie, AB	1991	NA[y]	May 7	Aug 24	303
	Crossfield, AB	1991	NA	May 6	Aug 31	299
	Carstairs, AB	1991	breaking	May 29	Sep 5	220
	Irricana, AB	1993	barley	May 6	Aug 24	356
	Airdrie, AB	1991	barley	May 10	Sep 3	303
	Irricana, AB	1996	fallow	May 19	Aug 28	233
	Red Deer, AB	1996	peas	May 14	Aug 30	204
	Yorkton, SK	1996	canola	Jun 5	Sep 12	211
	Irricana, AB	1997	wheat	May 14	Sep 2	250
	Red Deer, AB	1997	peas	May 1	Sep 9	268
	Red Deer, AB	1997	barley	May 2	Aug 25	273
	Olds, AB	1997	barley	May 12	Sep 23	150
	Red Deer, AB	1998	canola	May 8	Aug 24	286
Wheat	Crossfield, AB	1991	NA	May 5	Sep 12	285
	Crossfield, AB	1993	canola	May 15	Oct 1	337
	Barons, AB	1997	wheat	May 5	Aug 19	123
	Enchant, AB	1998	sugar beet	Apr 27	Aug 11	155
Winter wheat	Irricana, AB	1998	wheat	Sep 23	Aug 4	244
	Irricana, AB	1999	barley	Sep 16	Aug 27	339
	Herronton, AB	2000	canola	Sep 21	Aug 15	108
	Irricana, AB	2000	barley	Sep 20	Aug 24	358
	Herronton, AB	1999	wheat	Sep 17	Sep 2	314

[z] Growing season
[y] NA= not available

placement (seed row and side band) and four P fertilizer rates (13, 27, 40, and 54 kg P ha^{-1}), and also included a P fertilizer check (no P fertilizer applied).

All sites were direct seeded into the existing stubble from the previous crop either with an airseeder with six openers and 22.7 cm spacing or a hoe drill with six openers at 17.8 cm spacing. Seeding dates are summarized in Table 1. Cultivar choices, seeding rates, and seeding depth were based on recommended practices for the particular region. Phosphorus (monoammonium phosphate) was applied to all plots according to the treatment protocol. Nitrogen (urea), and in some instances potassium (K_2O) fertilizers, were applied at rates based on soil test recommendations. Weed and insects were controlled on a need basis with pesticides applied with label-recommended application parameters.

Data Collection

A composite soil sample from 0-15 cm was collected from each experimental site prior to establishing a trial and was submitted to a soil testing laboratory for routine analysis. Results from this analysis of select soil characteristics are shown in Table 1.

Emergence counts were determined at the two- to four-leaf growth stage as the average of two counts, each consisting of two 1-m row lengths, per plot. Days to maturity (DTM) were calculated assuming an average dry down rate of 2.5% per day using the following equation (Karamanos et al. 2004):

DTM = [(moisture at harvest - 35) / 2.5] + days (1) from seeding to harvest.

Plots were harvested using a Wintersteiger Nurserymaster Elite experimental combine. Seed samples were dried at 60^{o}C by forced air, weighed to determine seed yield. The seed yield per plot was calculated with moisture content corrected to 13.5 and 10% for cereals and canola, respectively.

Statistical Analysis

Analyses were conducted using the MIXED procedure of SAS (Littell et al. 2006). The effects of sites (location by year combinations) and replicate were random, and the effects of P management treatment considered fixed. All P treatment combinations, including the check, were collated into a single factor for the analysis. Exploratory analyses revealed that residual variances were heterogeneous among sites. Therefore, the repeated statement was used to model heterogeneous residual variances. The AICc (corrected Akaike's information) model fit criterion confirmed whether the preceding model parameterization was better than a model including the random of replicate. Contrasts were used to assess the effect of P fertilizer rate. A regression analysis of means was used to quantify/summarize effect of P fertilizer rate between and across placement levels.

Results and Discussion

Table 3 summarizes the analysis of variance results, which showed that P fertilizer application (average of all treatments receiving P fertilizer) vs. no P always increased yield. On the other hand, P fertilizer application never affected plant density. Cereal crops days to maturity was affected by P fertilization, but differences often were too small to be of practical importance (largest differences were about 1 day). Contrasts indicated that P fertilizer rate had varied effects on crop responses, and the nature of the response depended on the crop and the method of placement.

Greater rates of seed-placed P fertilizer had a negative, linear effect on canola plant density (Fig. 1). Phosphorus fertilizer rate did not influence canola plant density when side-banded and yield regardless of placement (Fig. 1). Barley and spring wheat plant density were not affected by P fertilizer rate or placement (Fig. 1). Greater rates of seed-placed or side-banded P fertilizer resulted in a similar positive curvilinear effect on barley yield; P fertilizer rates of about 50 kg P ha^{-1} resulted in barley yields about 0.6 Mg ha^{-1} greater than when no P fertilizer was applied (Fig. 1). Greater rates of seed-placed or side-banded P had a positive, linear effect on spring and winter wheat yield (Fig. 1), with one exception. The linear effect for spring wheat receiving seed-placed P was not statistically significant ($P = 0.222$). The wheat yield advantage associated with the preceding statistically significant trends, excluding the exception, indicated that the highest P fertilizer rate versus no P fertilizer increased yield by about 0.2 Mg ha^{-1} for spring wheat and by about 0.6 Mg ha^{-1} for winter wheat.

Variance estimates generally showed that treatment effects were consistent across sites (Table 3). The site by treatment variance estimate was no greater than 1% of the sum total variance associated with the effect of site, and almost always was not statistically significant ($P > 0.05$). The only exception to proceeding occurred for winter wheat yield, where the site by treatment variance estimate was 10% of total variance associated with the effect of site.

There was no evidence that side banding P fertilizer would allow for greater ‘safe’ rates and consequent improvement in canola yields. Canola plant density was negatively affected by increasing P fertilizer rates (seed-placed only), but canola yield did not respond to P fertilizer rates regardless of placement method. Our stand responses agree with those of Lemke et al. (2009), but these authors found that canola yield was greater when P fertilizer was seed placed. The preceding indicates that under certain conditions the compensatory ability of canola to factors that negatively influence stand establishment. Previous research showed that less dense canola stands did not yield less, and that greater branching and increased pod retention at each node compensated so that canola yield was unaffected by stand density especially when the reduced plant population was uniformly distributed (Angadi et al. 2003). Our results also suggest the canola was able to meet P nutrition requirements with P rates as low as 15 kg P ha^{-1} regardless of the method of placement. We found that P fertilizer treatment effects were consistent across sites, however, the fact we assessed canola responses at five sites and the fact our results differed to past research indicated that results we noted may not always occur.

Cereal crops typically cannot adjust yield components as well as canola to situations where stand density is compromised. Consequently, we would expect that cereal yield responses would correspond with stand responses to P fertilizer rate/placement. However, barley and wheat stands tolerated all rates of P fertilizer regardless of placement method in our study, which means that cereal crops tolerate greater rates of P regardless of placement early in the growing season. Our results for cereal stand responses agree with those of Mooleki et al. (2010). Also, positive yield effects with greater P fertilizer rates, when no effect on plant stand was observed, suggests that barley, and spring and winter wheat seeds and seedlings are more tolerant to a salt effect than canola. It should be noted that the consistent lack of effect for P fertilizer rate/placement (i.e., relatively small site by treatment variance estimate) is likely more a reality for barley (13 sites). However, plant density was only assessed at one site for spring wheat, which makes it difficult to be certain that we should expect spring wheat density not to be responsive to P fertilizer rate/placement at other location and year combinations.

There was one exception cereal crop response to P fertilizer rate/placement. Spring wheat yield responded positively to greater rates of side-banded P fertilizer, and this represented the only instance that fit with our hypotheses; i.e., side banding P will allow crops to respond positively to greater rates of P fertilizer. Although Mooleki et al. (2010) did not examine the effect of P fertilizer rate, they found that spring wheat yield was greater with side banding versus seed placement under dry conditions. There are few plausible reasons for the preceding trends. Side-banding may place P fertilizer in a better position for roots to better meet temporal nutritional demands of spring wheat, especially when drier (data not shown). It is also possible, that negative effects on spring wheat stand when P fertilizer was seed-placed were not detected (only one site), which ultimately caused spring wheat not to be responsive to greater rates of seed-placed P fertilizer. However, the limited number of sites for spring wheat do not allow for a full interpretation of the results.

Results from this study showed that overall responses to P fertilizer rate/placement were relatively consistent.

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Table 3. Analysis of variance summary for crop responses to P fertilizer treatments for crop data collected at number locations in AB, 1991-2000.

	Canola			Barley			Spring wheat			Winter wheat
Effect / Contrast	Density	Days to maturity	Yield	Density	Days to maturity	Yield	Density	Days to maturity	Yield	Yield
					(P value)					
Treatment	0.051	0.751	0.269	0.645	0.001	0.000	0.234	0.668	0.301	0.000
Placement (P)	0.004	0.598	0.350	0.074	0.124	0.309	0.485	0.885	0.742	0.459
Check vs. all P[z]	0.098	0.660	0.041	0.903	< 0.001	< 0.001	0.422	0.145	0.043	0.000
Seed row: Rl	0.006	0.829	0.073	0.655	0.001	< 0.001	0.858	0.306	0.222	< 0.001
Seed row: Rn	0.492	0.271	0.129	0.849	0.044	0.009	0.092	0.392	0.253	0.792
Side band: Rl	0.892	0.507	0.109	0.217	0.002	< 0.001	0.929	0.258	0.057	< 0.001
Side band: Rn	0.769	0.913	0.806	0.859	0.396	0.010	0.256	0.714	0.762	0.694
					(Variance estimate)[y]					
Site	2627	124	0.551	759*	114**	1.55**	[x]	405	4.42	0.304
Site x Treatment	6	< 1	0.001	4	1**	0.01		< 1	< 0.01	0.034**
	(< 1)	(< 1)	(< 1)	(1)	(1)	(1)		(< 1)	(< 1)	(10)

[z] Comparison of treatment received no P fertilizer vs. all treatments receiving P fertilizer.

[y] Statistical significance of variance estimates is indicated as follows: '*' = $0.05 \geq P$ value ≥ 0.01; and '**' = P value < 0.01. The percentage variance (in brackets below the variance estimates) associated with each site by treatment interaction was calculated as the variance estimate for this interaction divided by the sum of the total variance associated with the effect of site.

[x] Wheat density was only assessed at one site.

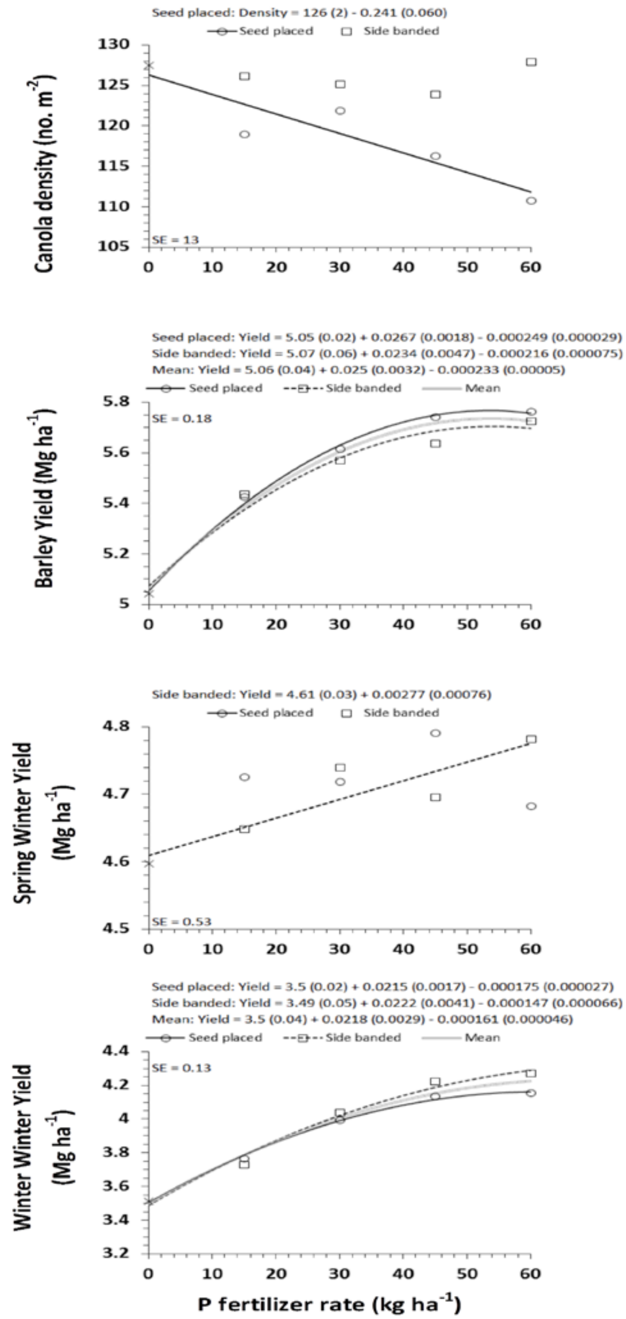

Fig. 1. Selected crop responses to P fertilization for data collected at a number of locations in AB, 1991-2000. Trend lines and regression equations were not fitted for responses to P fertilizer rate that were not statistically significant ($P < 0.05$) for a given level of P placement (Table 3). Regression equations were as follows: Response = Intercept (SE: standard error) + linear slope coefficient (SE) + quadratic slope coefficient (SE). An average (mean) trend across P placement was fit when responses to P fertilizer rate were significant for both seed placed and side banded P. Means derived from analysis of variance are also included along with their SE (inset into each chart).